

Biological Synopsis of the Bloody Red Shrimp (*Hemimysis anomala*)

Jérôme Marty

Fisheries and Oceans Canada
Great Lakes Laboratory for Fisheries and Aquatic Sciences
867 Lakeshore Rd., P.O. Box 5050
Burlington, ON L7R 4A6 CANADA

March 2008

**Canadian Manuscript Report of Fisheries
and Aquatic Sciences 2842**



Fisheries and Oceans
Canada

Pêches et Océans
Canada

Canada

Canadian Manuscript Report of Fisheries and Aquatic Sciences

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However no restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual indexes to scientific and technical publications.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Report (Biological Series) of the Fisheries Research Board of Canada. Numbers 1426-1550 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Manuscript reports are produced regionally but are numbered nationally. Request for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport manuscrit canadien des sciences halieutiques et aquatiques

Les rapports manuscrits contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes normaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. Il n'y a aucune restriction quand au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus de résumé de chaque rapport. Les rapports manuscrits sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 900 de cette série ont été publiés à titre de manuscrits (série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de rapports manuscrits de Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Les rapports manuscrits sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur donc le nom figure sur la couverture et de la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 2842

2008

Biological Synopsis of the Bloody Red Shrimp
(*Hemimysis anomala*)

by

J. Marty

Fisheries and Oceans Canada
Great Lakes Laboratory for Fisheries and Aquatic Sciences
867 Lakeshore Rd., P.O. Box 5050
Burlington, ON L7R 4A6 CANADA

© Her Majesty the Queen in Right of Canada, 2008
Cat. No. Fs 97-4/2842E ISSN 0706-6473

Correct citation for this publication:

Marty, J. 2008 Biological synopsis of the Bloody Red Shrimp (*Hemimysis anomala*). Can. Manuscr. Rpt. Fish. Aquat. Sci. 2842: viii + 36p.

ABSTRACT

Marty, J. 2008. Biological synopsis of the Bloody Red Shrimp (*Hemimysis anomala*).
Can. Manusc. Rpt. Fish. Aquat. Sci. 2842: viii + 36p.

The blood red shrimp (*Hemimysis anomala*) has the potential to cause great ecological threats in Canadian waters. The department of Fisheries and Oceans Canada is conducting a risk analysis to determine the ecological risk that this species poses in Canada. As the first step toward the risk analysis, a synopsis summarizing information on the biology of *H. anomala* was required. *H. anomala* is a mysid native from the Ponto-Caspian region. In the middle of the 20th century, *H. anomala* with a number of other Ponto-Caspian mysids were deliberately introduced to lakes and reservoirs of Eastern Europe with the intention of increasing fish production. A few decades later, *H. anomala* has extended its distribution to Western Europe. In 2006, it was first reported in the Great Lake basin (Lake Michigan and Ontario). At this point, no ecological effect of *H. anomala* has been found in the Great Lakes but several alterations are predicted if the expansion continues to increase.

RÉSUMÉ

Marty, J. 2008. Exposé Synoptique sur la Biologie de la Crevette *Hemimysis anomala*.
Can. Manusc. Rpt. Fish. Aquat. Sci. 2842: viii + 36p.

La crevette *Hemimysis anomala* pourrait être responsable d'importantes altérations écologiques dans les eaux Canadiennes. Pêches et Océans Canada souhaite conduire une étude de risques afin de déterminer les effets potentiels de l'invasion de cette espèce au Canada. Dans ce but, cet exposé synoptique vise à rassembler les informations sur la biologie de *H. anomala*. *H. anomala* est une espèce native de la région Ponto-Caspienne. Dans les années 1950, elle fut introduite volontairement dans plusieurs lacs et réservoirs Eurasiens afin d'accroître la production piscicole. En quelques décennies, *H. anomala* a envahi l'Europe de Ouest. In 2006, cette espèce a été observée pour la première fois dans le bassin des Grands Lacs (Lacs Michigan et Ontario). Aujourd'hui, aucun impact écologique de *H. anomala* n'a été reporté pour les Grands Lacs malgré que de nombreuses altérations soient prédites si l'expansion de l'espèce se poursuit.

TABLE OF CONTENTS

ABSTRACT.....	iii
RÉSUMÉ.....	iv
1-INTRODUCTION.....	1
2-NAME AND CLASSIFICATION.....	1
4-DESCRIPTION.....	2
4.1-Visual Aspect.....	2
4.2-Morphological Details.....	3
5-DISTRIBUTION.....	4
5.1-Native Distribution.....	4
5.2-Non-Native Distribution and Invasion History in Europe.....	4
5.3Non-Native Distribution and invasion history in North America.....	6
6-BIOLOGY AND NATURAL HISTORY.....	7
6.1-Reproduction and Growth.....	7
6.2-Population Dynamic.....	9
6.3-Physiological Tolerances and Behaviour.....	10
6.4-Habitat.....	11
6.5-Feeding and Diet.....	13
7-CONSERVATION STATUS.....	14
8-IMPACTS ASSOCIATED WITH INTRODUCTION.....	14
9-REFERENCES.....	19

LIST OF TABLES

Table 1: Locality, year of collection and of the first literature record. Number refers to sites presented in Figure 3. River kilometers are numbered by convention in downstream (*) or upstream (†) order. S (‰), salinity in parts per thousand. Modified from Audzijonyte *et al.* (2007).

Table 2: Summary of monitored sites in the Great Lake Basin (Source: National Center for research on Aquatic Invasive Species 2007). USGS: United States Geological Survey, DFO: Department of Fisheries and Oceans Canada, OMNR: Ontario Ministry of Natural Resources, INSH: Illinois Natural History Survey, NOAA GLERL: National Oceanic and Atmospheric Administration- Great Lakes Environmental Research Laboratory.

Table 3: Hydrological and physicochemical characteristics of sampling stations from Eastern Europe where *Hemimysis anomala* (modified from Whittmann (2007)).

LIST OF FIGURES

Figure 1: Color photography of *Hemimysis anomala* (body size:6-8 mm), reproduced with the permission of S. Pothoven (Photo Credits: NOAA, Great Lakes Environmental Research Laboratory (http://www.glerl.noaa.gov/hemimysis/hemi_photo_gallery.html)).

Figure 2: Color photography illustrating the anatomy of *Hemimysis anomala* as well as of other North American freshwater Mysids. (A) lateral view, (B) dorsal view, (C) pleopod IV, (F) outer ramus of antenna II, (I) endopod of uropod, and (J) telson. Male *Mysis relicta* from Lake Superior: (D) pleopod IV, (G) outer ramus of antenna II, and (K) telson. Male *Taphromysis* from Mississippi River: (E) pleopod IV, (H) outer ramus of antenna II, and (L) telson. Reproduced with the permission of S. Pothoven (NOAA, Great Lakes Environmental Research Laboratory) from Pothoven *et al.* (2007).

Figure 3: European distribution, range extension for *Hemimysis anomala*. Black symbols and bold numbers indicate samples used for genetic analysis in Audzijonyte *et al.* (2007). White symbols, italic numbers denote the year of the first finding (modified and updated after Wittmann, 2007), man-made canals are shown in dashed double lines. MLK, Mittellandkanal.

Figure 4: Map of site occurrence in the Great Lakes region. *Fish Samples are samples taken from the gut contents of fish which have been confirmed as *Hemimysis anomala*. Gut contents leave some uncertainty as to the exact location at which the fish may have consumed the shrimp. Source: NOAA, Great Lakes Environmental Research Laboratory web site (2007). (http://www.glerl.noaa.gov/hemimysis/hemi_reports.html)

Figure 5: Simple linear relationship between *Hemimysis anomala* brood size (number of eggs) and female length. Data were numerized from Ketelaars *et al.* (1999). The equation of the relationship is: Brood size = $-14.2 + 3.7 \times \text{Length}$ ($r^2=0.45$, $n=120$, $p<0.0001$).

Figure 6: Length-frequency distribution of *Hemimysis anomala* in Lake Michigan basin in November 2006. $n = 236$. Reproduced from Pothoven *et al.* (2007).

Figure 7: Length–weight relationships of *Hemimysis anomala* from Lake Reeserward (Lower Rhine, Germany), based on data from 4 sampling periods. Yellow: September 2002, Red: December 2002, Blue: February 2002 and Green: April 2003. The equation of the relationship is: $\text{Log}_{10} \text{Weight} = -2.78 + 2.26 \times \text{Log}_{10} \text{Length}$ ($r^2=0.6$, $n=158$, $p<0.0001$). Data were numerized from Borcharding *et al.* (2006).

Figure 8: Mean abundance (CPUE) of *Hemimysis anomala* at three depth levels in Lake Reeserward for the different daylight conditions; significant differences are marked with small letters (Bonferroni post hoc test, $P < 0.05$). From Borcharding *et al.* (2006).

Figure 9: Reported potential impacts on the food web associated with the introduction of *H. anomala*. This figure indicates the cascading effects of *H. anomala* on other levels of the food-web. A population dominated by juveniles will reduce algal biomass which in turn will reduce zooplankton production with further collapse of higher trophic levels (planktivorous and piscivorous fish). On the other hand, a population dominated by adults feeding on zooplankton will induce the collapse of fish population and also could increase algal production by higher release of nutrients (via fecal pellets mineralization) and removing grazing pressure. Beside food-web dynamic effects and based on effects observed for other mysids, the expansion of *H. anomala* is likely to increase the bioaccumulation transport of contaminants to predators.

1-INTRODUCTION

In the middle of the 20th century, Ponto-Caspian mysids were deliberately introduced to lakes and reservoirs of Eastern Europe with the intention of increasing fish production. A few decades later, several species had extended their distribution in Western Europe and to the Great Lakes Basin. These introductions yielded mild to severe modifications of the food web in these ecosystems which had further effects on humans (Ricciardi 2007). Among the Ponto-Caspian species who succeeded in their invasion is *Hemimysis anomala*, the bloody red shrimp. In 2006, it was found in two locations in the Great Lakes. *H. anomala* is predicted to extend its distribution in the near future, if not already, to large areas of the Great Lakes basin (Pothoven *et al.* 2007). As the first step toward a risk assessment in Canada, this synopsis aims to present the characteristics, the ecology and the known impacts of *H. anomala*.

2-NAME AND CLASSIFICATION

From ITIS database (2007).

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea, Brönnich, 1772
Class:	Malacostraca, Latreille, 1802
Subclass:	Eumalacostraca, Grobben, 1892
Superorder:	Peracarida, Calman, 1904
Order:	Mysida, Haworth, 1825
Family:	Mysidae, Haworth, 1825

Genus: *Hemimysis*, Sars, 1869
Species: *Hemimysis anomala*, G. O. Sars, 1907

Common scientific name: *Hemimysis anomala*, G. O. Sars, 1907

Common English name: bloody red mysid (shrimp)

Common names in other languages: Dutch: *Kaspische Aasgarnaal*, German:

Schwebegarnele, Finnish: *Kaspianhalkoisjalkainen*, Russian: *Myzida anomal'naya*,

Swedish: *Röd pungräka*, *Röd immigrantpungräka*, Ukrainian: *Myzida anomal'na*.

Voucher Specimens: Canadian Museum of Nature, Ottawa [CMNC 2007-0001]

4-DESCRIPTION

4.1-Visual Aspect

Hemimysis anomala is ivory-yellow in colour or translucent and exhibits pigmented red chromatophores in the carapax and telson (Salemaa & Hietalahti 1993, Janas & Wysocki 2005) (Fig. 1). The intensity of colouration varies with the contraction or expansion of the chromatophores in response to light and temperature conditions (Salemaa & Hietalahti 1993, Ketelaars *et al.* 1999, Pothoven *et al.* 2007). Short term changes in colour have been observed, including darker organisms in shaded environments (Salemaa & Hietalahti 1993). Juveniles are more translucent than adults (Ketelaars *et al.* 1999). Preserved individuals may lose their colour. Total length of the

males is 8–10 mm, females are slightly longer, typically up to 11 mm in the summer (Bacescu 1954, Komarova 1991), and even up to 16.5 mm in winter (Bacescu 1940).

4.2-Morphological Details

A detailed review of *H. anomala* morphology is given by Pothoven *et al.* (2007) and summarized below. The taxonomic classification of mysids is based on the morphology of the adult male (Pothoven *et al.* 2007). *H. anomala* can be distinguished from other mysid species, including the Great Lakes native opossum shrimp, *Mysis relicta*, by its characteristically truncated telson that is spined along its entire margin and has a wide, straight posterior margin (Fig. 2J–L). The genera *Mysis* and *Taphromysis* are characterized by a bifurcated tip of the telson (Fig. 2K, L), whereas in the genera *Neomysis* and *Deltamysis* the distal margin of the telson is narrowly truncated and/or convex at the tip (Smith 2001). The form of the telson is not subject to gender dimorphism in *H. anomala*, although immature and adult *H. anomala* may have a telson with an apical cleft (Reznichenko 1959 in Pothoven *et al.* 2007). Male *H. anomala* can be further discriminated from male *Neomysis* and *Deltamysis* by an exopod on pleopod IV with over three segments (Fig. 2C). In *Neomysis* and *Deltamysis*, the exopod on pleopod IV consists of two or less segments (Smith 2001). An elongated exopod on pleopod IV consisting of six or seven segments serve to distinguish male *Hemimysis*, *Taphromysis* and *Mysis* from all other mysid genera in North America (Fig. 2C–E). Male *H. anomala* and male *Mysis* differ in two respects: (1) pleopods V consist of two rami each with over three segments in *Hemimysis*, whereas those of *Mysis* consist of one unsegmented ramus (Birshtein 1968 in Pothoven *et al.* 2007) and (2) outer ramus on

antenna II (antennal scale) is elongate with a distinct terminal segment, which at the point of insertion on the outer ramus is more than a third of the largest outer ramus width in *Hemimysis* (Fig. 2F), while *Mysis* has a narrowly lanceolate antennal scale with an indistinct terminal segment, which at the point of insertion on the outer ramus is less than a quarter of the largest outer ramus width (Fig. 2G).

5-DISTRIBUTION

5.1-Native Distribution

H. anomala is an endemic Ponto-Caspian species and has been observed in the coastal regions of the Caspian, Black and Azov seas, in their lagoons and up to 50 km upstream in the rivers Don, Dnestr, Dniepr, Pruth and Danube (Bacescu 1954, 1966, Dediu 1966, Komarova 1991, in Wittmann 2007). It was originally found across a wide range of salinities, ranging from 18 ‰ to freshwater (Bacescu 1954, Mordukhoy-Boltovskoi 1979, Komarova, 1991). Before human manipulations, *H. anomala* was known as an estuarine or marine species, penetrating less than 60 km into river reaches (Wittmann 2007).

5.2-Non-Native Distribution and Invasion History in Europe

Historically, few mysids expanded their distribution in the continental waters of Europe before the 1950s (Wittmann 2007). In the late 1940s, a massive intentional introduction of mysids began in several Eastern European reservoirs, lakes and rivers, with the objective of increasing fish production. Although poorly reported, one hundred

million mysids (*Paramysis*, *Limnomysis* and *Hemimysis*), together with a great variety of other invertebrates (*Gammarus lacustris*, *Dikerogammarus haemobaphes* and *Corophium curvispinum*) (Gasiunas 1968, Borodich & Havlena 1973, Mordukhai-Boltovskoi 1979) were introduced to more than 200 water-bodies of the former Soviet Union between 1948 and 1965 (Wittmann 2007). In the 1980s, most of the intentional introductions of mysids stopped when the adverse effects of these introductions on the food web of recipients ecosystems were recognized (Ketelaars *et al.* 1999, Wittmann 2007). However, ceasing intentional introductions had no direct effect on the ongoing invasion of the organisms (Wittmann 2007). During the following decades, as a result of increasing navigation traffic and the opening of new navigation routes, several Eurasian nonindigenous species (mussels (*Dreissena polymorpha*, *D. bugensis*), crustaceans (*Nitocra incerta*, *Schizopera borutzkyi*, *Cercopagis pengoi*, *Echinogammarus ischnus*), and fishes (*Neogobius malanostomus*, *Proterorhinus marmoratus*)) were able to extend their distribution outside of their watershed, invade central and western European waters and subsequently the Great Lakes (Grigorovich *et al.* 2003, Pothoven *et al.* 2007). Among mysids, four species were particularly successful in their expansion into central and western Europe: *Hemimysis anomala*, *Paramysis lacustris*, *Katamysis warpachowskyi* and *Limnomysis benedeni* (Wittmann 2007).

In the 1950s and 1960s, *H. anomala* was intentionally introduced into several impoundments on the River Dniepr (Ukraine), water reservoirs near Chernorechensk and Simferopol on the Crimean peninsula, and the Dubossary reservoir (Moldavia) (Zhuravel 1960, Komarova 1991). In 1962, *H. anomala* was first found outside of the Ponto-

Caspian basin when it was transferred from the Dniepr hydropower reservoir to reservoirs in Lithuania (Kaunass reservoir on the River Nemunas) (Gasiunas 1968, Mordukhai-Boltovskoi 1979). Further expansion in Europe was reported for the Baltic Sea (1992, Salemaa & Hietalahti (1993)), the River Rhine and Danube basin (1997-1998, (Wittmann 2007)), and the United Kingdom English Midlands (2004, (Holdich *et al.* 2006)) (see Table 1 for a summary of occurrence). Based on information from the mitochondrial DNA of *H. anomala*, Audzijonytes *et al.* (2007) were able to identify two routes of invasion into northern and western Europe (Fig. 3). The first route started in the lower Dnieper River (northwest Black Sea) and expanded toward the Baltic Sea and further to the Rhine delta. Another distinct pathway occurred from the Danube Delta and spread across the continent via the Danube River and down to the River Rhine via the Danube canal. The Danube lineage was responsible for the invasion of England and North America (Audzijonytes *et al.* 2007). According to the most recent samples analyzed, both lineages are now mixed in Europe (Audzijonytes *et al.* 2007).

5.3-Non-Native Distribution and Invasion History in North America

The invasion of *H. anomala* along with 16 other Ponto-Caspian species was predicted in the Great Lakes basin, via direct transmission from the Ponto Caspian basin or by secondary invasion sites (Ricciardi & Rasmussen 1998, Grigorovich *et al.* 2003), despite the ballast water-regulations implemented in 1993. In 2006, the first occurrence of *H. anomala* was reported in the Lake Michigan basin, near Muskegon Lake (Pothoven *et al.* 2007) and in southern Lake Ontario at Nine Mile Point near Oswego, NY (Kipp & Ricciardi 2007). These occurrences very likely resulted from ballast water release from

transoceanic ships (Kipp & Ricciardi 2007). Because of concealment behaviour and difficulty collecting *H. anomala* using traditional net tows, it is possible that its invasion remained undetected for many years in the Great Lakes (Reid *et al.* 2007). Previous study has shown the similarity in the invasion pattern between *H. anomala* and *Echinogammarus ischnus* (Cristescu *et al.* 2004) and it is likely that both organisms were introduced into the Great Lakes during the same time period (1998), when *E. ischnus* was first reported (Pothoven *et al.* 2007). Over the last two years, three of the Great Lakes (Michigan, Erie and Ontario) have been confirmed as invaded (Fig. 4, Table 2).

Today, there is considerable effort in place to report *H. anomala* sightings in the Great Lakes basin via the *Hemimysis anomala* Survey & Network (National Center for research on Aquatic Invasive Species 2007). New confirmed and potential sightings can be reported at mysis.glerl@noaa.gov and this information is used to update the list of sites of occurrence for the Great Lakes.

6-BIOLOGY AND NATURAL HISTORY

6.1-Reproduction and Growth

H. anomala, as with all peracarid crustaceans, requires sexual reproduction. *H. anomala* breeds from April to September/October. Water temperature has an important effect on the development of *H. anomala* by limiting the number of broods per year (2-4, Ioffe 1973) and could therefore limit its expansion into colder areas. According to Mordukhai-Boltovskoi (1960), most female *H. anomala* from the Caspian region produce

at least two broods, although more studies should be conducted on this topic as the number of generations per year remains uncertain (Borcherding *et al.* 2006). Ovigerous females generally appear when the water temperature reaches 8-9°C and neonates can be observed in the marsupium when the temperature reaches 11-12°C. Given these temperatures, *H. anomala* breeds from April to September in the Biesbosch reservoirs (The Netherlands) (Ketelaars *et al.* 1999), although ovigerous females were found as late as November in Lake Michigan (Pothoven *et al.* 2007). In the Baltic Sea, breeding females were found in October and fully developed oocytes were observed in late April, indicating the long breeding period for *H. anomala* compared to other mysids found in the northern Baltic (Salemaa & Hietalahti 1993). Variation in brood size has been reported according to seasons with higher brood size in the spring (29 ± 10.9) compared to the end of summer (20 ± 3.6) (Borcherding *et al.* 2006). The number of eggs per brood generally varies from 2 to 70 and is correlated to female length (Ketelaars *et al.* 1999; Salemaa & Hietalahti 1993, Borcherding *et al.* 2006, Pothoven 2007). Specifically, based on data retrieve from Ketelaars *et al.* (1999), brood size (number of marsupial oostegites) can be predicted using the following linear regression model based on female length (mm) (Fig. 5):

$$\text{Brood size} = -14.2 + 3.7 \times \text{Length} \quad (r^2=0.45, n=120, p<0.0001)$$

There is no evidence that this equation could be applied to the Great Lakes where the mean size of *H. anomala* is smaller than measured in Europe (Pothoven *et al.* 2007). Further sampling would be required to collect a larger number of individuals (only two

samples were collected in November 2006, Grigorovich (Wilson Environmental Laboratories) pers. comm.).

The development of young individuals does not require a naupliar stage but instead directly follows several life instars that are differentiated according to body length. The number of stages varies from 4 to 6, depending on authors and/or *Mysis* species (Borodich & Havlena 1973). After 45 days, at the end of stage IV, the individuals reach sexual maturity. Similarly to all arthropods, *H. anomala* has a chitinous exuvia that sheds during growth.

6.2-Population Dynamics

The number of organisms found at a given site varies greatly, which limits our ability to produce reliable density estimates. In the Great Lakes, the finding of a single organism is often reported although higher densities, comparable to that of eastern Europe, have been reported in Lake Michigan (Table 2) (Pothoven *et al.* 2007). Extremely high densities of *H. anomala*, up to $>6 \text{ ind} \cdot \text{L}^{-1}$, were recorded in eastern Europe reservoirs (Ketelaars *et al.* 1999). Within a population of *H. anomala*, the density of adults is generally greatest from November to the end of summer (Ketelaars *et al.* 1999). During this time period, the number of females is generally greater than males (Ketelaars *et al.* 1999). Similar variations in sex ratio were also reported in the Great Lakes (Pothoven *et al.* 2007) (Fig. 6) and may be related to male mortality after breeding and longer lifespan of females compared to males (Ketelaars *et al.* 1999).

Borcherding (2006) reported changes in the length-weight relationship of virgin females based on sampling periods (see Fig. 3 in Borcherding et al. (2006)). Although relationships of each sampling period were statistically significant, it is important to note that they differed greatly in their portion of explained variance (from 9 to 56%). Based on the overall data set, a better length-weight relationship could be constructed as follows (Fig. 7):

$$\text{Log}_{10} \text{ Wet weight} = -2.78 + 2.26 \times \text{Log}_{10} \text{ Length} \quad (r^2=0.6, n=158, p<0.0001)$$

In this equation, units are in mg and μm for weight and length respectively. The length was measured from the tip of the rostrum to the tip of the telson.

6.3-Physiological Tolerances and Behaviour

The main hydrological and physiological characteristics of a series of eastern European ecosystems with *Hemimysis* are presented in Wittmann (2007) (Table 3). Although most mysids are found in marine environments, *H. anomala* is a brackish-water species, able to adapt to freshwater, shown by its invasion of various types of aquatic systems (seas, coastal shores, rivers, reservoirs and lakes). It is generally recognized that *H. anomala* is not sensitive to environmental variations which increases its probability of further expanding its distribution. For instance, in contrast with most other mysids, *H. anomala* has the ability (along with *E. ischnus*) to survive and reproduce under a wide range of salinities (from 0.1 to 18, Table 3) (Wittmann 2007), which may have facilitated its survival during intercontinental transportation in ballast waters (Pothoven *et al.* 2007, Reid *et al.* 2007).

Water temperature is reported to influence *H. anomala* development and growth. Based on field observations, this organism has been reported to occur in water temperature ranging from 0-28°C, however, its preferred temperature range is 9-20°C (Ioffe 1973, Kipp & Ricciardi 2007). As previously mentioned, low temperatures have been related to decreases in the number of eggs per broods (Ioffe 1973). Low temperatures may also reduce the growth rate of adults by direct physiological effects or indirectly by reducing the food resources available (Borcherding *et al.* 2006). Populations are able to survive over the winter when water temperatures approach zero, but not without substantial mortality (Borcherding *et al.* 2006). However, Dumont (2006) observed large and active swarms under cold water conditions (3°C) and even under frozen lake surfaces.

6.4-Habitat

H. anomala is ubiquitous to all types of water-bodies from salt to freshwater. It is a sublittoral species (Salemaa & Hietalahti 1993), living in a wide range of depths (from the surface to 50m). In Lake Reeserward (Germany), *Hemimysis anomala* was mostly found in surface waters (0-3 m) and mid-depth waters (4.5-9 m) (Borcherding *et al.* 2006). A deeper depth distribution has, however, been occasionally reported (20 m in the Black Sea, 30 m in the Caspian Sea (Bacescu 1954) and up to 50m in the Dnieper reservoir (Zhuravel 1960)).

H. anomala is nektonic and actively swims back and forth within a swarm (Salemaa & Hietalahti 1993) that can be abundant enough to occupy several square meters of area (Dumont 2006). *H. anomala* can move very quickly in the water column, up to a speed of several centimeters per second (Borcherding *et al.* 2006). Because of its fast reaction to disturbance, sampling methods used for mysids may be inadequate and should be adapted to fast swimming organisms (Borcherding *et al.* 2006). The swarm avoids direct light and high flow velocity by aggregating above deep sediments or under rocks, in cavities or cracks and crevices during the day and disperses at night to feed in the sublittoral zone (Salemaa & Hietalahti 1993, Dumont 2006). When at the bottom, *H. anomala* was found on hard/rocky sediment rather than on soft/silty substrate (Pothoven *et al.* 2007). In addition, *H. anomala* is scarcely found in sites with dense vegetation (Pothoven *et al.* 2007). In many cases, *H. anomala* was found in anthropogenic habitats consisting of massive concrete shores (Pothoven *et al.* 2007, Wittmann 2007). In particular, most observations of *H. anomala* in Europe have been reported from harbours, reinforcing the hypothesis of ballast water release as a vector of introduction. The concealment behaviour makes *H. anomala* difficult to locate during the day, possibly explaining why it was not found earlier in the Great Lakes (Reid *et al.* 2007). Further, the concealment behaviour of *H. anomala* indicates a preference for slow moving waters, suggesting that flow velocity may limit the expansion of this organism. Again, no data are available to support this hypothesis but flow may be a variable to consider when localizing potential sites of invasions.

Adult *H. anomala* migrates diurnally in the water column. During daylight, swarms remain in dark areas but migrate to the upper water column at dusk where they

feed during the night until morning (Janas & Wysocki 2005, Borcharding *et al.* 2006) (Fig. 8). Juveniles do not migrate as much as adults because of their transparency, which make them less vulnerable to predation in the upper water column (Borcharding *et al.* 2006).

6.5-Feeding and Diet

To feed, *H. anomala* uses its thoracic limbs to capture preys with its endopods or to remove food particles from its body that are filtered by its exopods (Ketelaars *et al.* 1999, Borcharding *et al.* 2006). *H. anomala* may play a critical role in food web dynamics because it serves as a link between primary and secondary producers. It is able to adapt its feeding behaviour depending on food availability and exhibits ontogenetic changes in diet (Borcharding *et al.* 2006, Pothoven *et al.* 2007). *H. anomala* is generally reported as an omnivorous organism, with a high feeding rate (Ketelaars *et al.* 1999), feeding primarily on cladocerans zooplankton (*Daphnia* and *Bosmina*) and copepods and rotifers (Borcharding *et al.* 2006). According to Dumont (2006), *H. anomala* could also be detritivorous and cannibalistic. Based on gut content analysis from the Reesevard (Rhine region, Germany), detritus, phytoplankton (mainly diatoms and green algae), insect larvae may also be part of the diet of *H. anomala* (Borcharding *et al.* 2006). Feeding behaviour differs according to age with younger organisms (<4 mm length) relying to a larger degree (11 %) on algal material than adults (4 %). In contrast, the proportion of zooplankton in the diet reaches 26% for adults compared to 9 % for juveniles (Borcharding *et al.* 2006). Most of the variation in the feeding behaviour of large *H. anomala* is related to light conditions. During the day, the content of algal material in adults gut was significantly higher; the proportion of detritus increased with

depth. The proportion of zooplankton in the stomach of large organisms was higher at night (Borcherding *et al.* 2006).

7-CONSERVATION STATUS

H. anomala is considered endangered in several isolated Ukrainian localities including Dnieper-Bug Liman, the River Zelenaya draining into the Sea of Azov and Tiligul Liman in the northwestern Black Sea coast (Alexandrov 1999, Pothoven *et al.* 2007). *Hemimysis anomala* has been classified with a global conservation status of G5 (globally secure) (NatureServe 2007). The conservation status for the North America has not been assessed yet as the result of incomplete/unavailable information.

8-IMPACTS ASSOCIATED WITH INTRODUCTION

The early intentional introduction of *H. anomala* in lakes and reservoirs of Eurasia were intended to increase fish production. *H. anomala*, a lipid-rich organism, is comparable to fish or *M. relicta* as a high-quality energy food source (Borcherding *et al.* 2006). In the River Rhine, the contribution of *H. anomala* as prey for young-of-year (YOY) perch (*Perca fluviatilis*) varies from 20 to 100% (Borcherding *et al.* 2006). Further, based on a feeding experiment, YOY perch grew extremely fast when feeding on *H. anomala* (Borcherding *et al.* 2007). Stomach contents of Lake whitefish (*Coregonus clupeaformis*), contained no *H. anomala* in sites where the invader was found in Lake Michigan (Pothoven *et al.* 2007). Nonetheless, although not yet reported in the literature,

fish predation may limit the abundance of *H. anomala* and possibly explain why this invader is currently endangered in its native locations (J. Wittmann (Department of Ecotoxicology, Medical University of Vienna), pers. comm.). Parasitism may also threaten *H. anomala* from its native locations, with rust spotted illness that is a widespread illness in the Volga River basin and found in some individuals (Ioffe *et al.*, 1968).

H. anomala is omnivorous, with a high feeding rate and a reproductive rate of more than two broods per year (Ketelaars *et al.* 1999). In the Biesbosch reservoir (The Netherlands), the invasion of *H. anomala* caused a decline in both zooplankton and phytoplankton biomass (Ketelaars *et al.* 1999). Zooplankton community changes consisted in the disappearance of several cladocerans (*Daphnia* sp., *Bosmina* sp.) as well as rotifers and ostracods. Furthermore, carnivorous zooplankton (*Bythotrephes longimanus* and *Leptodora kindti*) also disappeared from this system, likely the result of resource competition and direct predation (Ketelaars *et al.* 1999). Based on laboratory feeding experiments, Ketelaars *et al.* (1999) found all zooplankton groups in the gut content of *H. anomala*, including predatory species. Uncertainties regarding the top-down effects of *H. anomala* on zooplankton exist when algal production is low and therefore limits zooplankton production (Ketelaars *et al.* 1999). In addition, possible effect of the decrease in zooplankton density on fish production because of *H. anomala* remains unknown and requires further study. Finally, further studies on the diet of *H. anomala* are required as current dataset are based on the analysis of a small number of organisms, over a rather short time period and for a limited number of ecosystems.

The predation of *H. anomala* on zooplankton also affects primary producers (Borcherding *et al.* 2006). This top-down interaction has been observed after the introduction of *Mysis relicta* in several ecosystems (Lasenby *et al.* 1986) and was responsible for the doubling of algal biomass in a Norwegian lake (Koksvik *et al.* 1999), suggesting the potential effect of invaders controlling primary producers via the reduction of grazing pressure. Grazing experiments and gut content analysis revealed the ability of *H. anomala* to feed on algal material (Ketelaars *et al.* 1999, Borcherding *et al.* 2006). Ketelaars *et al.* (1999) suggested that adult *H. anomala* may switch their diet toward algae when zooplankton production is low. As previously discussed, algae represents the preferred food for juveniles compared to adults (Borcherding *et al.* 2006). Therefore, the effect of *H. anomala* on algae depends on the abundance of young individuals and on the abundance of zooplankton as a food source for adults.

Although not specific to *H. anomala*, Ponto-Caspian invaders have also induced modifications to the physico-chemical properties of ecosystems (Leppäkoski & Olenin 2000, Ojaveer *et al.* 2002, Ricciardi 2007). As a result of its high predation rate relative to other mysids, the production of fecal pellets by *H. anomala* may increase the concentration of surface water nutrients (Ricciardi 2007). Additional release of dissolved organic compounds may also occur in systems where juvenile *Hemimysis* are present via their consumption of algal material (Ricciardi 2007).

In the Great Lakes, no effect on the food web has been detected following the occurrence of *H. anomala*, despite the many predicted consequences of its invasion (Ricciardi 2007). When a lack of information exists on the effects of a given invader in a given region, it is possible to predict its potential effects by 1- considering the reported effect of the organism in other regions where an invasion has already occurred and 2- by considering the effects of other similar invaders already present in the system. Based on these 2 empirical approaches, Ricciardi (2007) identified several possible threats of *H. anomala* invasion to the Great Lakes, summarized in Fig. 9.

The success of a new invader is usually dictated by its ability to occupy an ecological niche that is not already used by resident species (Ricciardi & Atkinson 2004). Ponto-Caspian species are phylogenetically (Audzijonyte *et al.* 2007) and ecologically (Ricciardi 2007) distinct from native species of the Great Lakes and therefore may find little barriers to their expansion. For example, *Mysis* are usually considered deep-water species, living in the hypolimnion and therefore have a restricted effect on the overall water column. In contrast, *H. anomala* is found in a wide range of depths, from pelagic to sublittoral habitats. Its concealment behaviour and/or deep-water migration during the day allow this organism to avoid fish predation and access resources in the surface water layers during the night. In addition to the predicted cascading effects of *H. anomala* on the food web of the Great Lakes, the invasion of *H. anomala* may increase the biomanification of contaminants in high trophic levels (Ricciardi 2007). For instance, previous studies have shown the importance of *Mysis* to increased mercury contamination in fishes by feeding in the littoral zone of lakes (Cabana *et al.* 1994).

ACKNOWLEDGEMENTS

Helpful information and data were provided by Steven Pothoven (NOAA, Great Lakes Environmental Research Laboratory), Igor Grigorovich (Wilson Environmental Laboratories), Karl Wittmann (Department of Ecotoxicology, Medical University of Vienna) and Jost Borcharding (Department of General Ecology and Limnology, Zoological Institute of the University of Cologne). Pauline Maupu (Environment Canada) and Sharon Van Den Oetelaar (St. Lawrence River Institute) provided bibliographic support. Chantal Vis (Parks Canada), Marten Koops (DFO), Becky Cudmore (DFO) and Jocelyn Gerlofsma (DFO) revised the early version of the manuscript. Funding was provided by the Centre of Expertise for Aquatic Risk Assessment, Fisheries and Oceans Canada.

9-REFERENCES

- Alexandrov B. 1999. Black Sea Environmental Internet Node. Marine Hydrophysical Institute.
- Audzijonyte, A., K.J. Wittmann, and R. Väinölä. 2007. Tracing recent invasions of the Ponto-Caspian mysid shrimp *Hemimysis anomala* across Europe and to North America with mitochondrial DNA. Diversity and Distributions, In press.
- Bacescu, M. 1940. Les Mysidacés des eaux Roumaines (Étude taxonomique, morphologique, biogéographique et biologique). Annales Scientifiques de l'Université de Jassy **26**:453-804.
- Bacescu, M. 1954. Fauna Republicii Populare Romine. Crustacea **4**:1-126.
- Bacescu, M. 1966. Die kaspische Reliktfauuna im ponto-asowschen Becken und in anderen Gewässern. Kieler Meeresforschungen **22**: 176-188
- Birshtein, Y.A. 1968. Order Mysidacea, p. 213-227. In [eds.], Y.A. Birshtein, L.G. Vinogradov, N.N. Kondakov, M.S. Astakhova, and N.N. Romanova Atlas of Invertebrates of the Caspian Sea. Pishchevaya Promyshlennost.
- Borcherding, J., B. Hermasch, and P. Murawski. 2007. Field observations and laboratory experiments on growth and lipid content of young-of-the-year perch. Ecology of Freshwater Fish **16**:198-209.
- Borcherding, J., S. Murawski, and H. Arndt. 2006. Population ecology, vertical migration and feeding of the Ponto-Caspian invader *Hemimysis anomala* in a gravel-pit lake connected to the River Rhine. Freshwater Biology **51**:2376-2387.
- Borodich, N. D., and F. K. Havlena. 1973. The biology of mysids acclimatized in the reservoirs of the Volga River. Hydrobiologia **42**:527-539.
- Cabana, G. A., A. Tremblay, J. Kalff, and J. B. Rasmussen. 1994. Pelagic food chain structure in Ontario lakes: a determinant of mercury levels in lake trout (*Salvelinus namaycush*). Canadian Journal of Fisheries and Aquatic Sciences **51**:381-389.
- Cristescu, M. E. A., J. D. S. Witt, I. A. Grigorovich, P. D. N. Hebert, and H. J. MacIsaac. 2004. Dispersal of the Ponto-Caspian amphipod *Echinogammarus ischnus*: invasion waves from the Pleistocene to the present. Heredity **92**:197-203.
- Dediu, I. I. 1966. Répartition et caractéristique écologique des Mysides des bassins des rivières Dniestr et Pruth. Revue Roumaine de Biologie - Zoologie **11**: 233-239

- Dumont, S. 2006. A new invasive species in the north-east of France, *Hemimysis anomala* G.O. Sars, 1907 (Mysidacea). *Crustaceana* **79**:1269-1274.
- Faasse, M. A. 1998. The pontocaspian mysid, *Hemimysis anomala* Sars, 1907, new to the fauna of the Netherlands. *Bulletin Zoölogisch Museum Universiteit Van Amsterdam* **16**:73-76.
- Gasiunas I. Akklimatizatsiya mizidii *Hemimysis anomala* Sars. [3], 71-73. 1968. Trudy Akademii Nauk Litovskoi SSR. vodokhranilishche Kaunasskoi GES.
- Grigorovich, I. A., R. I. Collautti, E. L. Mills, K. T. Holeck, A. G. Ballert, and H. J. MacIsaac. 2003. Ballast-mediated animal introductions in the Laurentian Great Lakes: retrospective and prospective analyses. *Canadian Journal of Fisheries and Aquatic Sciences* **60**:740-756.
- Holdich, D., S. Gallagher, L. Rippon, and P. Harding. 2006. The invasive Ponto-Caspian mysid, *Hemimysis anomala*, reaches the UK. *Aquatic Invasions* **1**:4-6.
- Ioffe, Ts. I. 1973. Pool for acclimatization of invertebrates in the USSR. *Izv. Gos. Nauchno-Issled. Inst. Ozer. Rechn. Rybn. Khoz.* **84**:18-68.
- Ioffe, Ts. I., Salazkin, A.A., and Petrov, V.V. 1968. Biological foundations for enrichment of fish food resources in the Gorkyi, Kuibyshev and Volgograd reservoirs. *Izv. Gos. Nauchno-Issled. Inst. Ozer. Rechn. Rybn. Khoz.* **67**:30-80.
- ITIS. The Integrated Taxonomic Information System (ITIS). ITIS . 2007.
- Janas, U., and P. Wysocki. 2005. *Hemimysis anomala* G.O. Sars, 1907 (Crustacea, Mysidacea)- first record in the Gulf of Gdansk. *Oceanologia* **47**:405-408.
- Kelleher, B., G. Van der Velde, K. J. Wittmann, M. A. Faasse, and A. Bij de Vaate. 1999. Current status of the freshwater Mysidae in the Netherlands: with records of *Limnomysis benedeni* (Czerniavsky 1882), a pontocaspian species in Dutch Rhine branches. *Bulletin Zoölogisch Museum Universiteit Van Amsterdam* **16**:89-94.
- Ketelaars, H. A. M., F. E. Lambregts-van de Clundert, C. J. Carpentier, A. J. Wagenvoort, and W. Hoogenboezem. 1999. Ecological effects of the mass occurrence of the Ponto-Caspian invader, *Hemimysis anomala* G.O. Sars, 1907 (Crustacea: Mysidacea), in a freshwater storage reservoir in the Netherlands, with notes on its autecology and new records. *Hydrobiologia* **394**:233-248.
- Kipp R.M. & Ricciardi A. *Hemimysis anomala*. 2007. Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS).
- Koksvik, J. I., H. Reinertsen, and A. Langeland. 1999. Changes in plankton biomass and species composition in Lake Jonsvatn, Norway, following the establishment of *Mysis relicta*. *American Fisheries Society Symposium* **9**:115-125.

- Komarova, T.I. 1991. Fauna of Ukraine. Naukova Dumka.
- Lasenby, D. C., T. C. Northcote, and M. Fürst. 1986. Theory, practice, and effects of *Mysis relicta* introductions to North American and Scandinavian lakes. Canadian Journal of Fisheries and Aquatic Sciences **43**:1277-1284.
- Leppäkoski, E., and S. Olenin. 2000. Non-native species and rates of spread: lessons from the brackish Baltic Sea. Biological Invasions **2**:151-163.
- Mordukhai-Boltovskoi, F. D. 1939. O reliktovoi faune nizovev Dona. Trudy Rostovskogo Oblastnogo Biologicheskogo Obshchestva **3**:69-76.
- Mordukhai-Boltovskoi, F.D. 1960. Caspian fauna in the Azov and Black Sea Basins. Moscow-Leningrad, Russ. SFSR, Izdatelstvo Akad. Nauk SSSR.
- Mordukhai-Boltovskoi, F.D. 1979. Composition and distribution of Caspian fauna in the light of modern data. Internationale Revue der gesamten Hydrobiologie **64**: 1-38
- National Center for Research on Aquatic Invasive Species. 2007. *Hemimysis anomala* Survey & Monitoring Network. National Oceanic and Atmospheric Administration.
- NatureServe. 2007. NatureServe Explorer: An online encyclopedia of life [web application]. [6.2]. Arlington, Virginia, NatureServe.
- Ojaveer, H., E. Leppäkoski, S. Olenin, and A. Ricciardi. 2002. Ecological impact of Ponto-Caspian invaders in the Baltic Sea, European inland waters and the Great Lakes: an inter-ecosystem comparison. Pages 412-425 in E. Leppäkoski, S. Gollasch, and S. Olenin editors. Invasive Aquatic Species of Europe - Distribution, Impacts and Management. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Pothoven, S. A., I. A. Grigorovich, G. L. Fahnenstiel, and M. D. Balcer. 2007. Introduction of the Ponto-Caspian bloody-red mysid *Hemimysis anomala* into the Lake Michigan basin. Journal of Great Lakes Research **33**:285-292.
- Rehage, H. O., and H. Terlutter. 2002. *Hemimysis anomala* Sars (Crustacea, Mysidacea) im Mittellandkanal bei Recke- Obersteinbeck (Nordrhein-Westfalen). Lauterbornia **44**:47-48.
- Reid, D. F., R. Sturtevant, and S. Pothoven. 2007. Calling on the public: where in the Great Lakes Basin is the newest aquatic invader, *Hemimysis anomala*? Aquatic Invaders **18**:1-7.
- Reznichenko, O.G. 1959. On ecology and morphology of mysids in the genus *Hemimysis*. Tr. Vses. Gidrobiol. Ova. **9**: 343

- Ricciardi, A. 2003. Predicting the impacts of an introduced species from its invasion history: an empirical approach applied to zebra mussel invasions. *Freshwater Biology* **48**:972-981.
- Ricciardi, A. 2007. Forecasting the impacts of *Hemimysis anomala*: the newest invader discovered in the Great Lakes. *Aquatic Invaders* **18**:1-7.
- Ricciardi, A., and S. K. Atkinson. 2004. Distinctiveness magnifies the impact of biological invaders in aquatic ecosystems. *Ecology Letters* **7**:781-784.
- Ricciardi, A., and H. J. MacIsaac. 2000. Recent mass invasion of the North American Great Lakes by Ponto-Caspian species. *Trends in Ecology and Evolution* **15**:62-65.
- Ricciardi, A., and J. B. Rasmussen. 1998. Predicting the identity and impact of future biological invaders: a priority for aquatic resource management. *Canadian Journal of Fisheries and Aquatic Sciences* **55**:1759-1765.
- Salemaa, H., and V. Hietalahti. 1993. *Hemimysis anomala* G. O. Sars (Crustacea: Mysidacea) – immigration of a Pontocaspian mysid into the Baltic Sea. *Annales Zoologici Fennici* **30**:271-276.
- Schleuter, A., H. P. Geissen, and K. J. Wittmann. 1998. *Hemimysis anomala* G.O. Sars 1907 (Crustacea: Mysidacea), eine euryhaline pontokaspische Schwebgarnele in Rhein und Neckar. *Lauterbornia* **32**:67-71.
- Smith, D.G. 2001. Minor Malacostraca, p. 545-551. *In* [ed.], D.G. Smith Pennak's freshwater invertebrates of the United States. John Wiley & Sons.
- Wittmann, K. J. 2007. Continued massive invasion of Mysidae in the Rhine and Danube river systems, with first records of the order Mysidacea (Crustacea: Malacostraca: Peracarida) for Switzerland. *Revue suisse de Zoologie* **114**:65-86.
- Wittmann, K. J., J. Theiss, and M. Banning. 1999. Die Drift von Mysidaceen und Dekapoden und ihre Bedeutung für die Ausbreitung von Neozoen im Main-Donau-System. *Lauterbornia* **35**:53-66.
- Zettler, M. 2002. Crustaceologische Neuigkeiten aus Mecklenburg-Vorpommern. *Archiv der Freunde der Naturgeschichte in Mecklenburg* **41**:15-36.
- Zhuravel P.A. Nova dla sistemy Dnipra mizida *Hemimysis anomala* Sars. *Dniprovskomi vodoemikh*. [1], 85-87. 1959. *Dopovidi Akademii Nauk Ukrainskoi RSR*.
- Zhuravel, P. A. 1960. The mysid *Hemimysis anomala* Sars (Crustacea, Malacostraca) in the Dnieper water reservoir and its feeding value for fishes. *Zoologicheskii Zhurnal*. **39**:1571-1573.

Table 1: Locality, year of collection and of the first literature record. Number refers to sites presented in Figure 3. River kilometers are numbered by convention in downstream (*) or upstream (†) order. S (‰), salinity in parts per thousand. Modified from Audzijonyte *et al.* (2007).

No.	Locality	S‰	Latitude	Longitude	Year	n	First record	Reference
Ponto-Caspian native range								
1	Russia: Caspian Sea basin, Volga delta	<1	45.83	47.84	2003	5	2003	(Audzijonyte <i>et al.</i> 2007)
2	Russia: Sea of Azov basin, Don delta	<1	47.17	39.33	2003	3	1930s	(Mordukhai-Boltovskoi 1939)
3	Ukraine: Black Sea basin, Dnieper delta	<1	46.6	32.58	2004	3	1957	(Zhuravel 1959)
4	Ukraine: Black Sea basin, Dnieper delta	<1	46.38	30.27	2005	5	1936	(Bacescu 1940)
5	Romania: Black Sea basin, Danube delta	<1	45.16	29.66	2006	3	≤1953	(Bacescu 1954)
Invaded localities								
6	Lithuania: Kaunas water reservoir	<1	54.89	24.04	2004	5	1967	(Gasiunas 1968)
7	Finland: Tvärminne, Gulf of Finland, Baltic Sea	6–7	59.92	23.45	2005	9	1992	(Salemaa & Hietalahti 1993)
8	Poland: Gulf of Gdansk, Baltic Sea	6–8	54.55	18.56	2006	10	2002	(Janas & Wysocki 2005)
9	Germany: Lake Schwerin, Mecklenburg-Vorpommern	<1	53.63	11.45	2005	8	2001	(Zettler 2002)
10	UK: Holme Pierrepont, Nottingham, England	<1	52.94	-1.1	2006	8	2004	(Holdich <i>et al.</i> 2006)
11	USA: Muskegon Channel, Lake Michigan, Michigan	<1	43.23	-86.34	2006–07	9	2006	(Pothoven <i>et al.</i> 2007)
12	The Netherlands: Rhine Delta, Maas, Biesbosch reservoir	~1	51.76	4.76	1998	2	1997	(Faasse 1998)
13	The Netherlands: near Dintel River, Rhine delta	1–2	51.66	4.37	2005	5	1998	(Kelleher <i>et al.</i> 1999)
14	Germany: Bad Honnef, Lower Rhine (rkm 640)*	0	50.63	7.21	2005	7	1997	(Schleuter <i>et al.</i> 1998)
15	Germany: Mittellandkanal between Weser and Ems rivers	1	52.31	7.63	2005	5	2001	(Rehage & Terlutter 2002)
16	Austria: Linz, Upper Danube (rkm 2133)†	0	48.32	14.31	2005	6	1998	(Wittmann <i>et al.</i> 1999)
17	Austria: Vienna, Upper Danube (rkm 1935)†	0	48.28	16.36	2005–06	13	1998	(Wittmann <i>et al.</i> 1999)
18	Hungary: Dunaújváros, Middle Danube (rkm 1578)†	0	46.96	18.96	2005	6	2005	(Wittmann 2007)
19	Serbia: Veliko Gradiste, Middle Danube (rkm 1059)†	0	44.77	21.52	2005–06	13	2005	(Wittmann 2007)
20	Bulgaria: Lower Danube (rkm 625)†	0	43.75	24.57	2006	3	2006	(Audzijonyte <i>et al.</i> 2007)
21	Romania: Lower Danube (rkm 299)†	0	44.35	28.02	2006	1	2006	(Audzijonyte <i>et al.</i> 2007)

Table 2: Summary of monitored sites in the Great Lake Basin (Source: National Center for research on Aquatic Invasive Species 2007). USGS: United States Geological Survey, DFO: Department of Fisheries and Oceans Canada, OMNR: Ontario Ministry of Natural Resources, INSH: Illinois Natural History Survey, NOAA GLERL: National Oceanic and Atmospheric Administration- Great Lakes Environmental Research Laboratory.

Region	Country	State or province	City	Source	Depth	Method of collection	Date	Presence/Absence	Number of specimens
Lake Erie	USA	NY	Dunkirk	USGS			Apr-07	P	1
	Canada	ON	Kingsville	DFO	25-50 cm above bottom	Bottle traps (12-24 hours) and zooplankton net (night)	20-Aug-07	P	
	Canada	ON	Port Dover	OMNR	5.5 m	White perch gut content	01-Aug-06	P	
	Canada	ON	Port Stanley	DFO	25-50 cm above bottom	Bottle traps (12-14 hours) and zooplankton net (night)	22-Aug-07	P	
	USA	PA	Presque Ile			Bottle traps	summer-fall 2007	A	
	USA	OH	Toledo			Dipnet sweeps	12-Nov-06	A	
Lake Huron	USA	MI	Thunder Bay, Alpena			Plankton tows and bottle traps	May-07	A	
Lake Huron-Georgian Bay	Canada	ON	Bying Inlet / Britt dock	DFO			10-Jul-07	A	
	Canada	ON	Midland Docks	DFO			11-Jul-07	A	
	Canada	ON	Parry Sound CG dock	DFO			09-Jul-07	A	
	Canada	ON	Pencanguishene	DFO			12-Jul-07	A	
	Canada	ON	Point Au Baril	DFO			10-Jul-07	A	
	Canada	ON	Snug Harbour	DFO			10-Jul-07	A	
Lake Michigan	USA	MI	Charlevoix			Multiple triplicate 500 micron vertical net hauls	Jun-07	A	
	USA	IL	Chicago	INHS	7m	Neuston net towed to the surface	31-Jul-07	P	1
	USA	MI	Elk Rapids	DFO			21-Jun-07	A	
	USA	MI	Escanaba	DFO	bottom of lake	Night sampling with a zooplankton net	24-Jun-07	P	
	USA	MI	Grand Haven					P	
	USA	MI	Ludington	DFO			20-Jun-07	A	
	USA	MI	Milwaukee	DFO		Pictures taken from divers	01-Aug-07	P	3
	USA	MI	Milwaukee	DFO	bottom of lake	Night sampling with zooplankton net	26-Jun-07	P	
	USA	MI	Donges Bay	Janssen		Trap and scuba observation	04-Sep-07	P	2 in trap 3 seen
	USA	MI	Bradford Beach	Janssen		Trap	27-Sep-07	P	15
	USA	MI	Muskegon	NOAA GLERL			07-Nov-06	P	1540 ± 333 individuals/m2

Table 2 (continuation)

Region	Country	State or province	City	Source	Depth	Method of collection	Date	Presence/Absence	number of specimens
Lake Michigan	USA	MI	Naubinway	DFO	25-50 cm above bottom	Bottle traps (12-14 hours) and zooplankton net (night)	22-Jun-07	P	
	USA	WI	Rowleys Bay	DFO	bottom of lake	Night sampling with zooplankton net	25-Jun-07	P	
	USA	WI	Sheboygan			Brown Trout gut content - may have been <i>Mysis relicta</i>	10-Mar-07	P?	
	USA	IL	Waukegan		10 ft	Yellow Perch gut contents	25-Sep-07	P?	
	USA	IL	Waukegan		9m	Yellow Perch gut contents	15-Aug-07	P?	
	USA	MI	West Traverse Bay			Multiple triplicate 500 micron vertical net hauls and bottle traps	Jun-07	P	
Lake Ontario	Canada	ON	Bowmanville	OMNR		Night nearshore surface tows	Sep-07	A	
	Canada	ON	Cobourg	OMNR		Night nearshore surface tows	Sep-07	P	
	Canada	ON	Collins Bay	OMNR		Night nearshore surface tows	Sep-07	A	
	Canada	ON	Hamilton Harbour, Burlington	DFO	2-3 m	Bottle traps	June 14	P	1
	Canada	ON	Hamilton Harbour, Burlington	DFO	2-3 m	Bottle traps	June 20	P	1
	Canada	ON	Hamilton Harbour, Burlington	DFO	25-50 cm above bottom	Bottle traps (12-14 hours) and zooplankton net (night)	June 15 & July 4	P	
	Canada	ON	Long Point	OMNR		Night nearshore surface tows	Sep-07	A	
	USA	NY	Olcott		1 m	Bottle traps	27-Jun-07	P	1
	USA	NY	Oswego	Normandeau Ass.	6m	Gillnets set overnight over rocky substrate	May-06	P	150
	Canada	ON	Pickering	OMNR		Found in the intake water samples at Pickering Nuclear Generating Station	Nov 22 & Dec 6, 2006	P	14

Table 2 (continuation)

Region	Country	State or province	City	Source	Depth	Method of collection	Date	Presence/Absence	number of specimens
Lake Ontario	Canada	ON	Presque Ile	OMNR		Night nearshore surface tows	Sep-07	P	
	Canada	ON	Whitby	OMNR		Night nearshore surface tows	Sep-07	P	
Lake St. Clair	Canada	ON	Lighthouse Cove and Belle River Marina	DFO			25-Jul-07	A	
Detroit River	Canada	ON	Windsor	DFO			July 16-17, 2007	A	
	Canada	ON	LaSalle	DFO			17-Jul-07	A	
	Canada	ON	Amherstburg	DFO			18-Jul-07	A	
St. Clair River	Canada	ON	Sarnia	DFO			July 23-24, 2007	A	
	Canada	ON	Port Lambton	DFO			25-Jul-07	A	
Welland Canal	Canada	ON	Port Colbourne	DFO	25-50 cm above bottom	Bottle traps (12-14 hours) and zooplankton net (night)	22-Aug-07	P	

Table 3: Hydrological and physicochemical characteristics of sampling stations from Eastern Europe where *Hemimysis anomala* (modified from Wittmann (2007)).

Variables	Mean	St. Dev.	min.	max.	n
<u>All samples:</u>					
Depth (m)	4.0	5.4	0	60	103
Water current ($\text{m}\cdot\text{s}^{-1}$)	0.2	0.2	0	0.8	98
Temperature ($^{\circ}\text{C}$)	17.2	4.5	2	28	78
Salinity	2.1	4.2	0.1	18	87
Conductivity ($\mu\text{S}\cdot\text{cm}^{-1}$)	3792.0	6947.0	279	29200	87
pH	7.9	0.5	6.4	8.7	63
Carbonate hardness ($^{\circ}\text{d}$)	8.6	975.0	6	12	60
Oxygen ($\text{mg}\cdot\text{l}^{-1}$)	7.2	1.4	4.0	10.8	63
Turbidity (NTU)	28.6	26.3	5	137	63
<u>All regions, drift samples excluded:</u>					
Water current ($\text{m}\cdot\text{s}^{-1}$)	0.0	0.1	0	0.4	69
<u>All sample types, samples in the Caspian Lake excluded:</u>					
Salinity	1.5	3.3	0.1	18	82
Conductivity ($\mu\text{S}\cdot\text{cm}^{-1}$)	2697.0	5486.0	279	29200	82

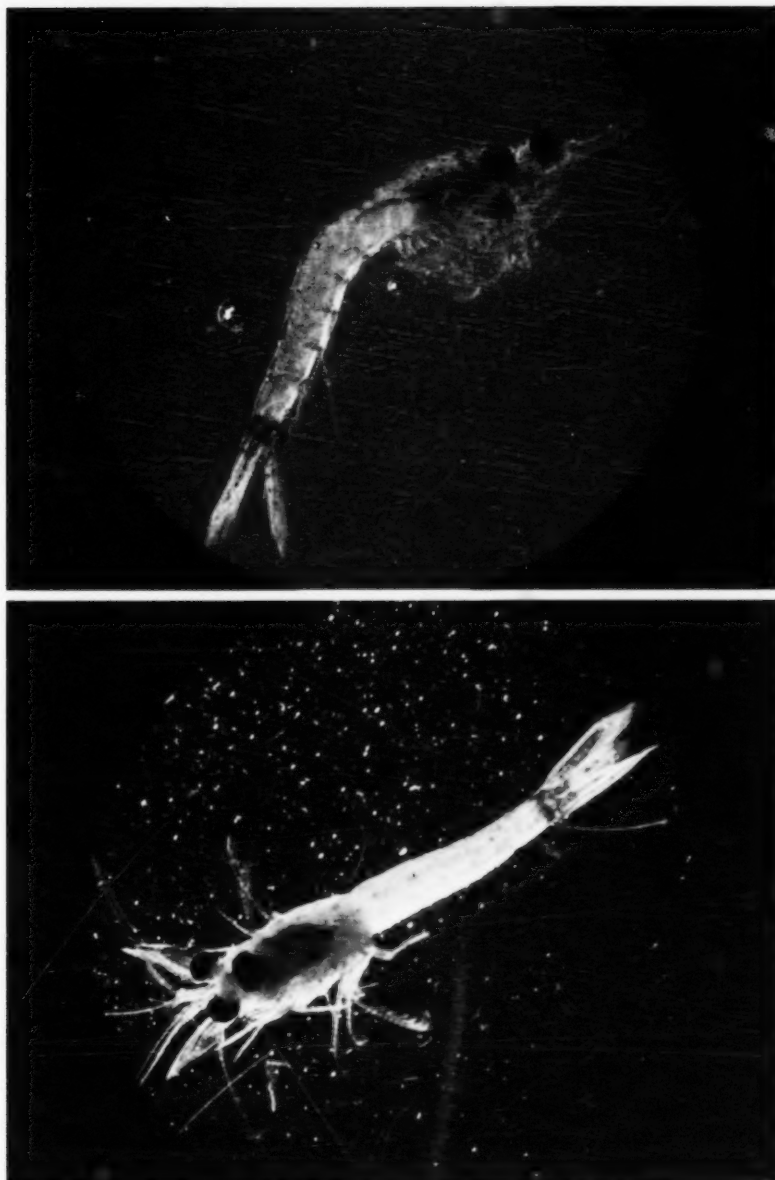


Figure 1: Close-ups of *Hemimysis anomala* (body size: 6 to 8 mm). Photo Credits: NOAA, Great Lakes Environmental Research Laboratory (http://www.glerl.noaa.gov/hemimysis/hemi_photo_gallery.html).

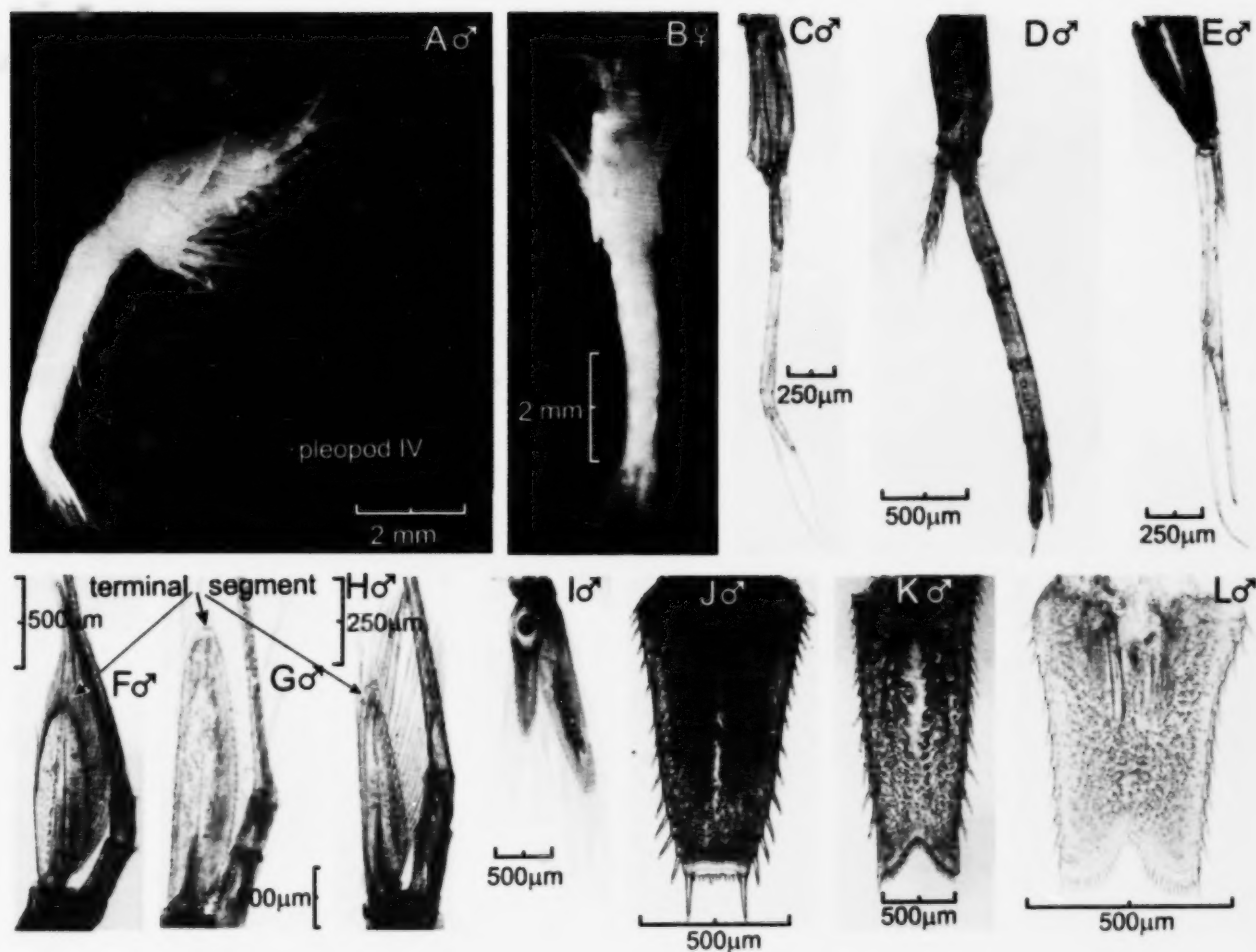


Figure 2: Morphological features of North American freshwater mysids. *Hemimysis anomala* from Lake Michigan basin: (A) lateral view, (B) dorsal view, (C) pleopod IV, (F) outer ramus of antenna II, (I) endopod of uropod, and (J) telson. Male *Mysis relicta* from Lake Superior: (D) pleopod IV, (G) outer ramus of antenna II, and (K) telson. Male *Taphromysis* from Mississippi River: (E) pleopod IV, (H) outer ramus of antenna II, and (L) telson. (reproduced from Pothoven *et al.* (2007)).



Figure 3: European distribution, range extension for *Hemimysis anomala*. Black symbols and bold numbers indicate samples used for genetic analysis in Audzijonyte *et al.* (2007). White symbols, italic numbers denote the year of the first finding (modified and updated after Wittmann, 2007), man-made canals are shown in dashed double lines. MLK, Mittellandkanal.



Figure 4: Map of site occurrence in the Great Lakes region. *Fish Samples are samples taken from the gut contents of fish which have been confirmed as *Hemimysis anomala*. Gut contents leave some uncertainty as to the exact location at which the fish may have consumed the shrimp. Source: NOAA, Great Lakes Environmental Research Laboratory web site (2007). (http://www.glerl.noaa.gov/hemimysis/hemi_reports.html)

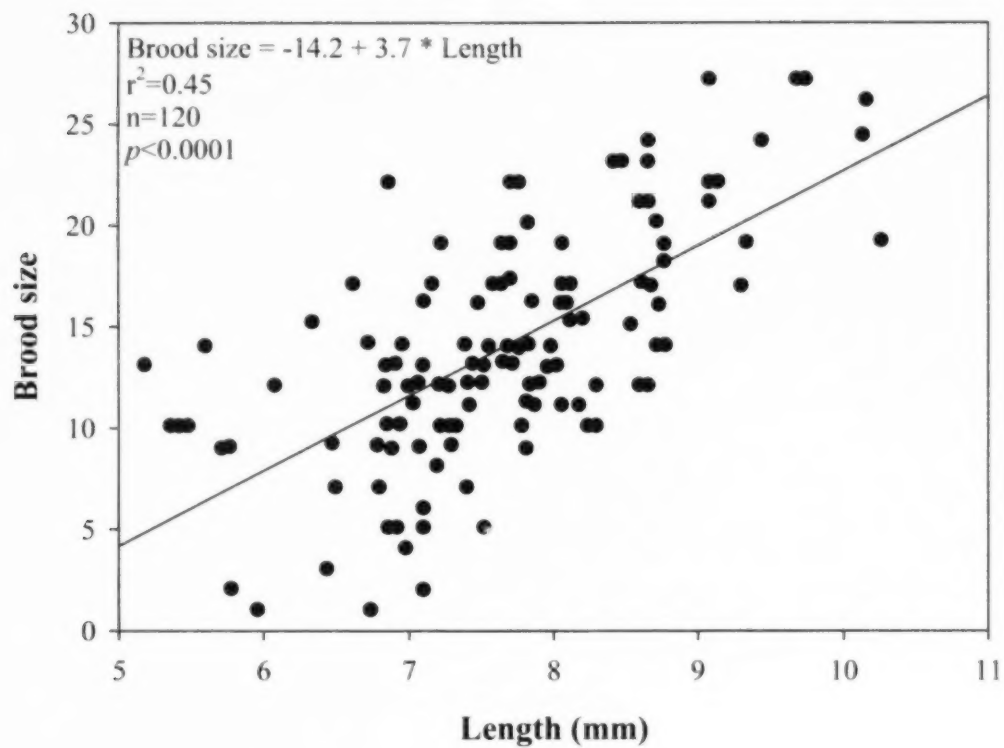


Figure 5: Simple linear relationship between *Hemimysis anomala* brood size (number of eggs) and female length. Modified from Ketelaars *et al.* (1999).

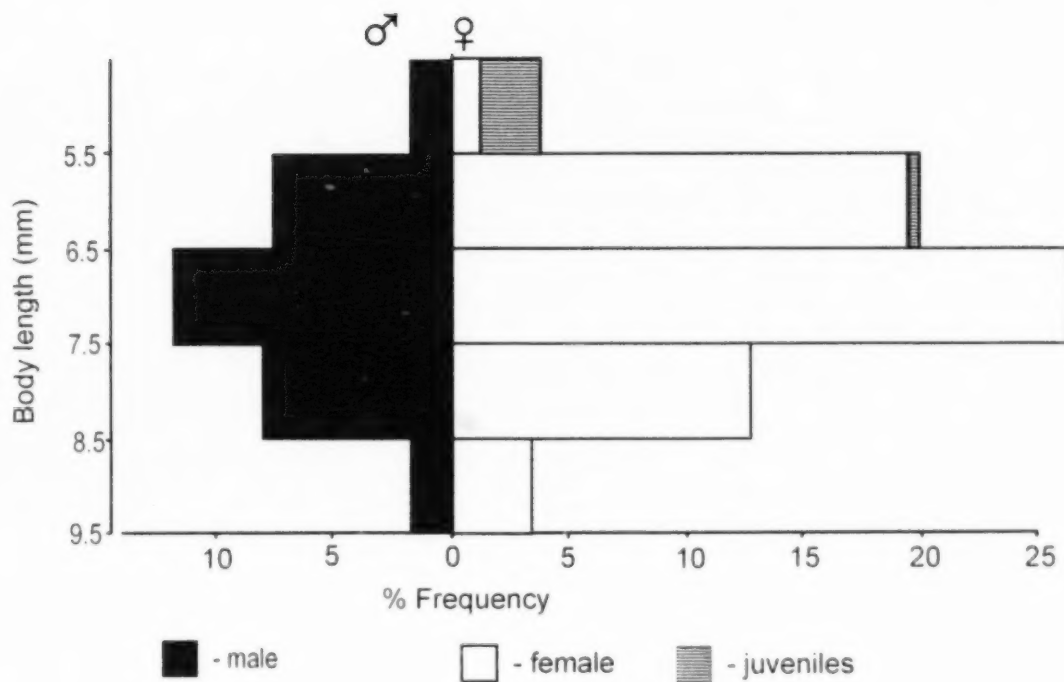


Figure 6: Length-frequency distribution of *Hemimysis anomala* in Lake Michigan basin in November 2006. n = 236. From Pothoven *et al.* (2007).

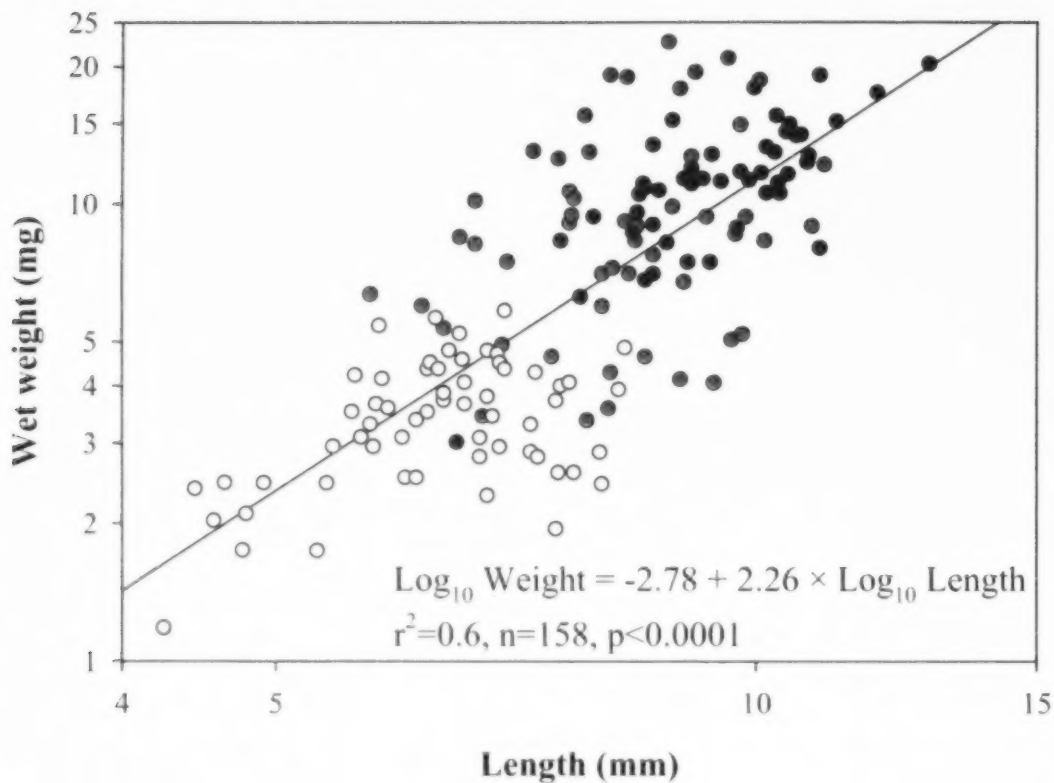


Figure 7: Length–weight relationships of *Hemimysis anomala* from Lake Reeserward (Lower Rhine, Germany), based on data from 4 sampling periods. Yellow: September 2002, Red: December 2002, Blue: February 2002 and Green: April 2003. Data retrieved from Borchering *et al.* (2006).

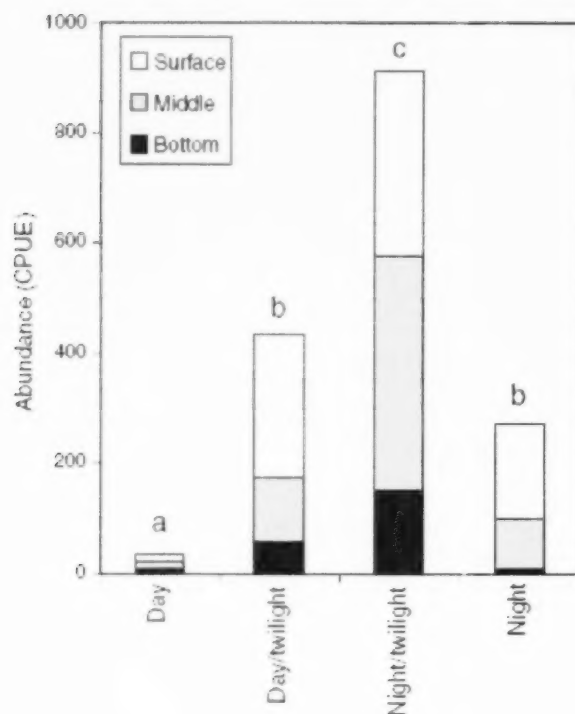


Figure 8: Mean abundance (CPUE) of *Hemimysis anomala* at three depth levels in Lake Reeserward for the different daylight conditions; significant differences are marked with small letters (Bonferroni post hoc test, $P < 0.05$). The time of day was characterised by four groups: day = the whole sampling period during the day; day/ twilight = the main part of the sampling period was during the day including a twilight period; night/ twilight = the main part of the sampling period was during the night including a twilight period; night = the whole sampling period occurred during the night. From Borcharding *et al.* (2006).

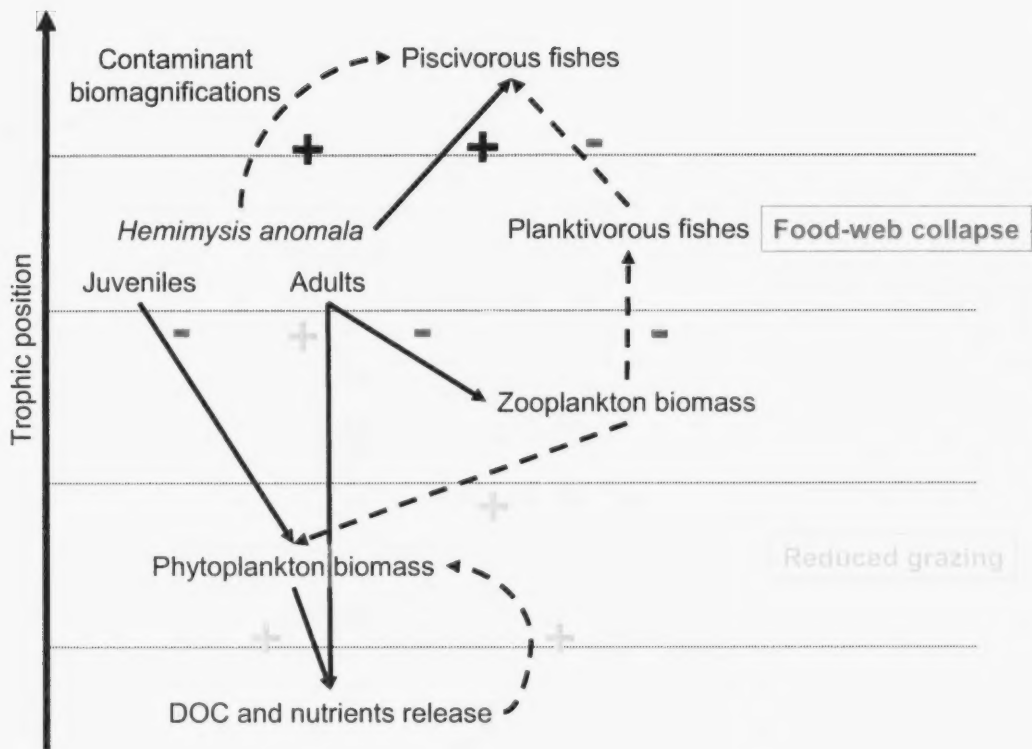


Figure 9: Trophic position of *Hemimysis anomala* in the food web and potential impacts (food web collapse, eutrophication and contaminant bioaccumulation) expected for the Great Lakes.



